Karlsruhe Institute of Technology

Sociotechnical Visions of 3D Printing – After the First Hype?

Report of the Vision Assessment Study in the Cluster of Excellence 3D Matter Made to Order

by Christoph Schneider[1], Maximilian Roßmann[1] and Andreas Lösch[1]

KIT SCIENTIFIC WORKING PAPERS 138

Information on affiliation:

[1] Institute for Technology Assessment and Systems Analysis (ITAS)

Acknowledgements:

The authors thank Alexandra Hausstein, Institute of Technology Futures (ITZ), for her advisory inputs.

The authors thank the Carl Zeiss Foundation for the financial support.

The Vision Assessment Study is part of the 3DMM2O Cluster funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany's Excellence Strategy – 2082/1 – 390761711.

Contact

Karlsruhe Institute of Technology (KIT),
Institute for Technology Assessment and Systems Analysis (ITAS),
Karlstrasse 11
D-76133 Karlsruhe

www.itas.kit.edu

Impressum

Karlsruher Institut für Technologie (KIT)
www.kit.edu

2020

ISSN: 2194-1629

Sociotechnical Visions of 3D Printing – After the First Hype?

Report of the Vision Assessment Study in the Cluster of Excellence 3D Matter Made to Order.

Authors: Christoph Schneider, Maximilian Roßmann and Andreas Lösch

March 2020

Table of contents

1 Introduction

How will 3D printing change the world? A grand question that seems to be naturally entwined with present desires, capabilities, and future promises about new and emerging technologies such as 3D printing. However, although one can only speculate about the future, managers, decision makers, researchers and politicians are routinely asked to disclose details about it, and to justify present actions accordingly. There is no certain knowledge about the future, but people determine actors on their statements. Therefore, Vision Assessment, an approach in the Technology Assessment methodological toolkit, asks a different question. Instead of making a statement about the actual future as it will happen, we study and assess the generation, negotiation, and contestation of socially imagined futures and their influence on present technology development.

In the discourse on 3D printing there is not only one vision of the future. Therefore, the key question of the Vision Assessment is divided into questions such as, what visions of the future are presently imagined and told about 3D printing? What are the differences in these sociotechnical imaginations, respectively in the imagined purpose, values, and attainable transformations of technology in society? Which societal actors and organizations engage in the generation and negotiation of visions? And how do the visions reflect the attitude of stakeholder regarding considered values, imagined power structures, and immutable facts? In sum, Vision Assessment studies the generation of imagined futures shaping the present (Grunwald, 2019a). It is a reflexive process that contributes to the social and democratic debates on visions of the future that guide collective action, planning, and technology development in particular. Vision Assessment is about fostering our present capacities to deal with and shape an open and uncertain future.

This is the first in a series of work in progress reports of the Vision Assessment study in the cluster of excellence 3D Matter Made to Order. With these reports, we would like to share the results of our empirical and analytical work on the societal role and aspects of visions of the future of 3D printing – and spark discussions and reflexivity amongst the 3D printing research community and the wider public. This report gives a brief overview of Technology Assessment and the arguments for assessing visions of the future of technologies through Vision Assessment. It argues for the relevance of such research in the early stages of technological research and development to have a perspective on the societal aspects of technologies. In the second part, we turn towards the results of exploring and analysing the visionary discourses and debates concerning 3D printing during the past two decades. We analytically distinguish key narratives that make up typical 3D printing visions. The report ends with a brief outlook on the next steps of our project and what you can expect to read in the next report.

The report gives insight into:

- ➔ An overview of Technology Assessment and the approach of Vision Assessment in fields of new and emerging technologies.
- ➔ The role of metaphors to assign meaning to new technologies, that is does it make a difference to speak about “3D printing” or “additive manufacturing”?
- ➔ Six key narratives that structure the discourse on futures of 3D printing.
- ➔ The history of the first societal hype of 3D printing.

2 Vision Assessment in the cluster of excellence

This chapter gives an introduction and overview of the background and motivations of Technology Assessment and Vision Assessment. The following questions are answered:

- ➔ What is Technology Assessment?
- ➔ What is the relevance of visions of the future for “visionary science” and society?
- ➔ What do we understand by “visions”?
- ➔ What does Vision Assessment do and what are its benefits?

2.1 Vision Assessment in Technology Assessment

Technology Assessment (TA) addresses the role of technological change and its consequences in society. It focuses on the “non-technical” aspects of technologies, so to say, with a view towards risks and opportunities of new technologies concerning ecological, social, ethical and economic criteria (Grunwald, 2019b). TA conceives of “technology” not as an isolated and autonomous force but as enmeshed in “sociotechnical” systems and processes, a part of society. That means technology is shaped by scientific, economic, political and other actors, relates to values and norms of everyday life of people and is spoken about, debated and contested through discourse and especially visions of the future. Society shapes technology as much as technology influences society.

TA as a field of scientific inquiry dates back to the 1960ies and 1970ies. The questions that TA researchers have been asking have changed since then together with the new technologies that have been introduced to society. What are or could be the environmental risks of new energy technologies? How do our work environments change due to automation technologies? What are the risks to privacy and the opportunities for participation linked to digital networks? Besides observing such consequences, TA provides research to foster societal capacities to deal with and actively shape technological change. To achieve this aim TA operates across different disciplines and in interaction with politics and society to gain insight and provide orientation through multiple perspectives. This is essential to understand the systemic and complex relationships between research, innovation, regulation, society, environment and the economy. Technology Assessment is carried out within science and at the level of the parliament, the public discourse, and in collaboration and exchange with research policymakers, engineers and scientists.

At Germany’s largest TA research organization, KIT’s Institute for Technology Assessment and Systems Analysis (ITAS), researchers with backgrounds in the social sciences, natural sciences, philosophy, environmental sciences, economics and engineering work in different research areas and often in interdisciplinary teams. ITAS’s director, Armin Grunwald, is also

director of the Office for Technology Assessment at the German Parliament that creates technology assessment reports for the Bundestag. Through different projects, ITAS is also involved in advising the European Parliament. However, due to the changing nature of technology and society, TA has to be flexible and inventive in its methods, formats, and audiences to foster societal capacities and more responsible research and innovation (Grunwald, 2019b). Thus, besides policy advice, technology assessment expertise is in different ways addressed towards different audiences and organisations in society.

One such change is the increasing relevance of “visionary science” (see McCray, 2013; Nordmann, 2016). This is a growing type of research central to fields such as nanotechnology, synthetic biology, artificial intelligence and more. The cluster of excellence 3D Matter Made to Order can also be seen as an example of visionary research. In its promise to shape the future, visionary research takes a special attitude towards research and society. Already in the research and development phase, a mutual exchange takes place about which current problems are to be solved by a focused orientation towards the future. This early exchange is contrary to a linear understanding of innovation, which assumes that research generates the basic knowledge that society subsequently uses to solve its problems. The social value of research is therefore not only attributed in the products, but already in the research process, the methods, studies and patents that have been developed, and also generally in the trained experts and the expertise gained. Conversely, visions of the future also shape these research fields. Many interdisciplinary fields such as nano-, bio- and information technologies orient their research towards visionary ideas. These ideas and visions about the possibilities and capabilities of technology are furthermore important to channel interactions of science with politics, industry, and society. While many technologies are often still confined to the laboratory, the visions of the future related to these new technical capabilities are taken up across society. Through such collective processes societies envision, debate, contest and shape their futures and in Vision Assessment we, therefore, often speak about “sociotechnical visions” that combine technological and social imaginations (Konrad & Böhle, 2019; Lösch et al., 2016).

The framing of research through such visions has the effect of influencing the early research agendas and the societal perceptions of new technologies. Visions often lead to decisions even before technologies have matured. To understand these decisions and reflect them in their social, political and economic significance, new innovation theories and methods of analysis have emerged with the concepts of "sociology of expectation" (Borup, Brown, Konrad, & van Lente, 2006), "sociotechnical imaginaries" (Jasanoff & Kim, 2013) "politics of expectations" (Beckert, 2016), and "assetization in technoscience" (Birch, 2019). What they have in common is the interest, analysis, and differentiation of imagined futures, their medial,

temporal and cultural dissemination, the attitude of different actors towards different imaginations of the future as well as the system-analytical assessment of the respective limits of their feasibility.

To understand and evaluate this it is necessary to analyze *how* the future is envisioned, how visions are taken up, discussed, contested and changed in different societal contexts, including science itself. In short, we need to understand how visions are used and what the effects of this are. That is why at ITAS we have developed the approach Vision Assessment as an element of Technology Assessment (Grunwald, 2019a; Lösch, Grunwald, Meister, & Schulz-Schaeffer, 2020; Lösch, Heil, & Schneider, 2017)

Vision Assessment with its focus on the use of visions of the future in the present does not claim to predict the future but to collect and compare different imaginations of the future under the assumption that these imaginations structure and evaluate present knowledge differently. This structuring is then compared with various stakeholder groups to work out which aspects, technologies and expertise are important for which future horizons and by whom. Focusing on imagined futures in the present helps to better understand how science and society shape the future. Vision Assessment is about revealing contexts and neglected boundaries to make more informed and robust decisions in the present – as researchers, politicians, entrepreneurs or citizens – by enquiring into the meanings that different actors and organizations assign to futures by using imagined futures.

> *"Policy-makers and society should understand what is going on scientifically and technologically, what is or might be at stake for future developments, where the grand challenges to society lie in relation to the fields under consideration, and who might be affected by societal developments based on progress. An open, democratic discussion of techno-visionary sciences is a prerequisite for a constructive and legitimate approach to shaping the future research agenda, regulations, and research funding." (Grunwald, 2019b, p. 34)*

2.2 What are visions and what do they do?

Visions are stories about desirable futures put forward by particular actors, i.e. individuals, organizations and networks of actors that often form around a shared technology or purpose. Besides being stories that people tell about the future they want, visions are part of practices at different levels. They are used to give meaning to activities and explain and legitimate imagined pathways to the future. Visions have consequences through being used in the present for different purposes. Planning, research, decision-making and in general social action are predominantly future-oriented. For example, hypotheses in research are designed in such a way at the basis of previous results that a controlled experiment promises to produce

new and valuable findings. Likewise, economic and political measures are oriented towards an imagined future based on current and previous communication. Imagined futures give meaning to present actions and the present development of technology. However, which restrictions of the past are considered for the imagined futures, which ideas are considered uncertain, and how the common knowledge is assembled into promissory stories is the subject of ongoing negotiations. Both consciously and unconsciously, imagined futures are contested by different stakeholders to put their measures in a good light – without actually knowing which measure will lead to success. At the basis of such externalisations and in exchange with stakeholders, this negotiation of socially imagined futures is studied as a communication process and discussed regarding the feasible pathways to the future.

In Vision Assessment we argue that the communication of visions has functions in research and innovation processes. Let's look at the vision of the 3D Matter Made to Order Cluster on the Cluster's website to give you an insight on what the Vision Assessment team means by that:

> *"The main task of the Cluster is to take 3D Additive Manufacturing to the next level. […] 3D Additive Manufacturing, or plainly speaking "3D printing", has the potential to change our world in the 21st Century as much as Gutenberg's movable-type "2D printing" did in the 15th Century. 3D Additive Manufacturing converts information – a digital blueprint – directly and rapidly into physical objects. […] This technology drastically shortens time to market, allows customization without additional cost, overcomes limitations of standard machining, and places the production of materials, objects, and functional devices from the hands of few factory owners into the hands of many with access to tabletop instruments with 3D printing capabilities. At the macroscale, 3D Additive Manufacturing of polymers and metals is already a megatrend worldwide."*
>
> https://www.3dmattermadetoorder.kit.edu/about.php, accessed February 2020

The narrative framing of 3D printing as a continuation of Gutenberg's project suggests that 3D printing will have a similar social significance for the good. Just as the letterpress broke the communicational dependence on scholars and induced major societal changes, 3D printing is considered to liberate production from the shackles of big companies, from limits to customization and product design, and from limits of collaboration.

Such visions have a societal function in practice, as we and other researchers in the field of societal expectations and imaginaries have shown: The generation, communication, and modification of visions hypothesizes and promotes social arrangements (e.g. Malone, Hultman, Anderson, & Romeiro, 2017; Mische, 2014). Imagined futures, vision, create a

tension between the present and the envisioned future (Ferrari & Lösch, 2017; Lösch et al., 2016; Lösch et al., 2017). A crucial insight is that the generation and contestation of visions is not a solitary practice of single persons but a societal practice that involves common believes and objectual lifeworlds. Therefore, socially imagined visions make a difference and shape the sociotechnical present. The analysis of present futures is therefore not a forecast. On the contrary, it helps to organize knowledge and actions in a considered way, which is helpful for the orientation towards a future. This knowledge is helpful because it provides an insight into the expectations and interpretative horizons of stakeholders. To make use of this knowledge about the future in the present, representations of this future knowledge must be sought, analyzed, summarised and generated. Vision Assessment offers an approach for the analysis, distinction, and assessment of visions and their practices that are essential for producing new knowledge and shaping social realities (Lösch et al., 2017):

- Visions create imagined *interfaces between the present and the future*. Using a vision of the future entails framing the present, its problems, and opportunities, in a certain way and envisioning particular changes, solutions, and novelties to emerge in the future. Visions are selective interpretations of the world.
- Visions serve as *communication media* by providing a shared, if often vague, imagined space that allows different people or organizations to communicate about the future. It is important to note that communication employing visions takes place without prior agreements because the visions provide the metaphors and structures of meaning. Visions can engender agreement, disagreement, contestation and lead to different interpretations of what needs to be done.
- Visions also have a *guiding function* by enabling different people and organizations to coordinate their actions. Visions can tie different actors together into research and innovation networks dedicated to advancing the ideas of the vision – for example, providing a narrative for a cluster of excellence such as 3DMM2O.
- Visions are often used to not only depict the expected future but to make statements about desirable futures. This *normative force* motivates people and organizations for action, to realize visionary ideas, or actively oppose them.

2.3 Vision Assessment at the interface of science, policy, and society

Science has the task to produce new knowledge and new technological capabilities. It shapes novelty and is a place of profound imagination of possible futures. Science takes part in society and is considered a special responsibility. Within science policy, society and science there is an increasing awareness of the power of science, research and innovation to change the

fortune and conditions of people, society and nature (e.g. Habermas, 2005; Jonas, 1979; Ladikas, Hahn, Hennen, Kulakov, & Scherz, 2019). There is also an increasing awareness that this power needs to be met with responsibility and that processes, methods, and institutions need to be found to make science and society mutually responsible and responsive. The United Nations (UN), the European Union (EU), and many national governments try to fund and foster this. Even Universities are becoming more aware of this. For example, KIT and the Technical University Munich have won, amongst other universities, in the Excellence Initiative with each explicitly stating the aim to work towards “Responsible Research and Innovation” (Schomberg & Hankins, 2019) in teaching and research. Science and science organisations are aware of the social challenges. They recognize how they have to position and correctly portray themselves to achieve economic, political and societal recognition – this is particularly evident in the award as the KIT became a university of excellence under the motto "living the change".

But how can responsible research and innovation look like in our global and complex society and how does the imagination of sociotechnical change come to life? In complex systems, when technological, economic, cultural, social, and political processes increasingly intertwine, centralistic patterns of problem solution face limits. The scientific inquiry needs to address and reflect its dynamic societal interdependencies. Interdisciplinary collaborations gather the knowledge of different disciplines to address common problems, and even transdisciplinary modes of scientific work are gaining traction and typically involve actors from outside of science in research and innovation projects. The special thing about these collaborations is that projects are worked on although no participant managed to foresee and plan all processes or could trace the considered knowledge back to a common ground. Cooperation takes place at the level of social practices. To give an example, guiding images instruct the participants to imagine a set of propositions without insisting that all that is imagined accordingly is exactly the same for all participants. Nevertheless, different actors can align their actions with the shared imagination. The Star Trek replicator, for example, is a device imagined in popular science fiction that is often cited by 3D printing researchers (e.g. Gershenfeld, 2007) to explain 3D printing and convey a possible vision of its future use. It serves for communication about the purpose of the technology and the imagination of everyday scenarios and it means a whole different thing for scientists and engineers who, within the framework of scientific and technological limits, deliberate on how to make it possible. Therefore, to steer and manage social complexity, people build on the increased self-reflexivity of science practice and its societal embedding. Science influences society and society influences science.

Fostering the interface and dialogue of science, policy and society is considered at the centre of European research policy (Owen, Macnaghten, & Stilgoe, 2012). This mission makes Vision

Assessment study part of the cluster of excellence. The interdisciplinary team considers different modes to foster collaboration and dialogue with scientists inside the cluster as well as with different actors and stakeholders in the adjacent and wider public (Figure 1).

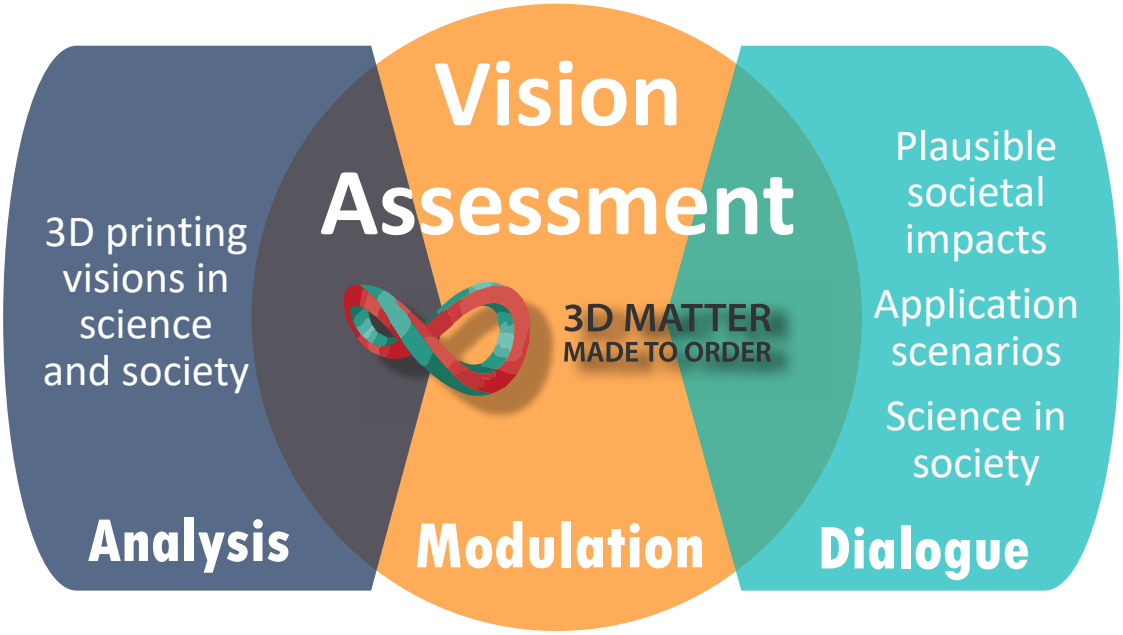

Figure 1: Vision Assessment is Analysis, Modulation, and Dialogue.

Analysis: With the means of empirical social science methods, we analyze and structure the visionary ideas and discourses that give meaning to 3D printing in the cluster and beyond and its relationships to society. The analysis aims to provide an overview of current visions of the future, their structuring function of current knowledge and projects, as well as an overview of the stakeholders involved in shaping them.

Modulation: To align the study for the benefit of the cluster, we are in an ongoing dialogue at different stages of the project. With the goal of RRI, this exchange should provide the opportunity to reflect scientific objectives and relationships in light of societal perceptions. We call this modulation and we aim to collaborate openly through different interdisciplinary formats and discussions.

Dialogue: Central to the study is the dialogue between science and society to foster societal understanding of the next generation of 3D printing technologies and to make science more responsive to societal debates. A core medium for these dialogues will be application scenarios tailored to the cluster's technologies that include technological and societal aspects and help to learn about and discuss 3D printing from different perspectives. Analysis, modulation and dialogue thus become part of a technology hermeneutic process that is aware of its social embedding.

Sociotechnical futures are not only the technical drafts to solve a perceived problem, but include the imagination of the technology in society, which assigns technology a normative meaning. Therefore, the guiding questions of our research focus on the differentiation of imagined futures of 3D printing: What are the different visions that shape pathways of 3D printing? Which societal implications are imagined? Which groups and actors push which vision of 3D printing? How can scenarios look like that combine technological and social change to facilitate a complex discussion of possible futures of 3D printing?

2.4 How can researchers in the cluster benefit from Vision Assessment?

Fostering creativity and responsible research:

Vision assessment helps to reflect present research and imagined futures in the bigger picture of societal trends and technology in society. Knowing and distinguishing visions helps to reflect on the present pathway of actions and to contrast alternatives. It opens up the social imagination to different public values. Deliberate and public communication about visions supports the democratic participation of different stakeholders and arguments to anticipate sociotechnical issues at an early stage.

Improving science communication:

Visions are an important medium for dialogues with stakeholders from society, politics, and industry. Being able to consciously use and reflect on visions enhances the dialogue. Such dialogues can become more open and democratic if visions are used reflexively and seen as one of many different possible futures. Through such visionary dialogue, society can debate possible futures early on.

3 The visions of 3D printing

This chapter is based on an analysis of visions that have been promoted about 3D printing. In the following you can read about:

- ➔ How do words and metaphors shape the imagination of 3D printing?
- ➔ How do the framings of 3D Printing and additive manufacturing frame technology in different perspectives?
- ➔ Which narratives underpin the main visions of 3D printing?

3.1 Making sense with metaphors: “3D printing” and “additive manufacturing”

Before we analyze the most common visions of 3D printing in this chapter, however, let’s look at a more basic way of how meaning is given through the usage of specific words. While it was long assumed that people derive decisions rationally from their goals and values, psychology, philosophy, cognitive science, and sociology suggest that weighing up actions is only possible in limited rationality (e.g. Blumenberg, 2009; Bruner, 1990; Kahneman, 2012; MacIntyre, 2007; McCloskey, 1999; Wittgenstein, 1984). Central to this is a pragmatic understanding of language that not only represents what is meant but also changes what is meant through language practice. Both in persuasion and cooperation with others as well as in the orientation of our actions we tend to follow shortcuts without an exact representation. Especially where highly specialized experts in diverse fields work together and are organized in projects, communication with metaphors and promissory stories is inevitable. In this way, communication structures emerge within internal organizations and in external communication. For the development of unproven technology, the orientation towards imagined futures turned out to be central. Therefore, this section focuses on the stories and metaphors of 3d printing.

“3D printing” or “additive manufacturing” are the words typically used to denote certain digital technologies able to manipulate matter. What is and what is not considered 3D printing or additive manufacturing has shifted over time. The meanings that these notions convey can be analyzed through the lens of metaphors. Metaphors are used to understand a certain domain of experience in terms of another, e.g. “love is a battlefield” conveys the idea that love is like war and that there is violence, winners and losers in love. Metaphors allow understanding the new in the words of the known. And crucially, metaphors activate mental frames, the basic building blocks of ideas that are integral to cognition, moral evaluation, and emotion. Seeing certain words as metaphors shows their importance in shaping the human understanding of aspects of reality (Lakoff & Johnson, 2003; Maasen & Weingart, 2000).

3.1.1 The metaphor of “3D printing”

Printing, in the Gutenberg universe, means to materialize, reproduce and distribute symbols and knowledge in forms of texts and images. Printing rather emphasises information than matter. Since nowadays printing is merely a desktop practice using a computer to print text and pictures, the metaphor also suggests being a standard arrangement for digital practices at home and in the office. The idea of a personal 3D printer has been widely taken up by the media and many companies to promote small, rather inexpensive machines for the private, networked, and digital life. Therefore, the metaphor of „3D printing” emphasizes replication, distribution and communication as well as the personalized of the technologies at home.

3.1.2 The metaphor of “additive manufacturing”

“Additive manufacturing” induces the context of industrial manufacturing processes. The historical denotation of manual work of the craftsmen (Latin: manus “hand”) has shifted its meaning to the industrial production of things in the early industrial revolution. Some stories also highlight the new-found potential of high-tech production on a small scale akin to the historical meaning with craftsmen. Since contrasting “Additive” to “subtractive” presupposes some industrial and manufacturing knowledge, this metaphor has less resonance with everyday experience than “3D printing”, and hence, is harder to communicate in public.

➔ *“3D printing” or “additive manufacturing”, which metaphor do you consider more appropriate for your research?*

However, there are 3D printing visions in which the different metaphorical meanings blur. Some visions, for example, suggest a new relationship between the individual or private usages and industrial production. Representations of these visions address different imaginaries and bring them into a common context. If too many facets are mingled, it quickly becomes clear that the imagination becomes implausible. For example, the cover picture of *The Economist* was a centrepiece publication in shaping and representing the 3D printing hypes around the year 2012. By representing the ambiguous imaginations an ironic attitude becomes apparent, which shows the contingency of imagination. This picture shows an imagined radical dissolution of boundaries between social contexts and forms of work: An amalgamation of PC desktop use and classical industry within the living room producing hammers, cars, and planes on an assembly line while drinking a coffee. Boosting the narrative of a new industrial revolution the picture suggests a mix of the “knowledge work” of the digital service economy and the machinery of the old industrial world. Indeed, one “revolutionary” aspect of digitalization is precisely a shifting and partly a dissolution of boundaries that existed in pre-digital modernity (Castells, 2011). However, these boundaries often still exist in transformed ways. There are still different contexts in which 3D printing is developed, used, regulated and imagined. In the

following, we turn to these and to the visionary ideas that are often closely related to social contexts.

Figure 2: The cover illustration of The Economist shows how metaphorical imaginaries are interwoven. (https://www.economist.com/leaders/2012/04/21/the-third-industrial-revolution)

3.2 Structures of the visionary discourse: key-narratives of 3D printing

Stories have a double meaning for dealing with imagined futures. On the one hand, they serve to build up mental frames (Lakoff, 2010). Mental frames are the mental contexts in which we perceive facts. On the other hand, these stories represent fictional pathways of how technology development is imagined. To assess the meaning and purpose of an action, investment or decision in the present, one either follows a proven routine or imagines a sequence of events set in motion. Pronouncing this sequence means telling a story. Narrating is the instruction to imagine a story. The audience of the story is supposed to imagine the said and to complement the imagination with own beliefs and experiences so that a social imagination about turning points or commitments for action emerge. Stories make sense out of events and propose to make fictional experiences. Roland Barthes, therefore, sees stories as intermediaries between a proposition on a topic and its significance for the discourse (Barthes & Heath, 1987). As a representation of a story, the wording of visionary narratives is less crucial as opposed to the metaphorical or poetic representations of imagined futures. Unlike metaphors and symbols, narratives represent time and action – they represent sites for hypothetical pathways to action.

The best-known form of future representation is the scenario. Scenarios instruct propositional imagination to uncover unconscious beliefs and technically neglected connections (Kahn &

Wiener, 1967; Kosow, Gaßner, Erdmann, & Luber, 2008). In interaction with models, scenarios serve to define boundary conditions for modelling and policies, by highlighting the significant and the differences from normal beliefs. In the same way, a visionary narrative instructs to imagine the temporal context from the antecedents and the initial idea of technology (A) to its realization and implantation in society (B), via failures, challenges, considered experiments, prototypes, and the highlighted features of a technology (C). The significance of such "artificially" closed sequences of events (A to B via C) is already explained in Aristotle's poetics (Aristoteles, 2006) and serves as a starting point in literary theory and rhetoric. However, the perspective has received new attention, when literary methods were used to analyze how economists, judges, historians, and innovation managers make, contest and negotiate their choices of relevant events (Nash, 2010; White, 1980). In contrast to the spurned, classical rhetoric, the scientific analysis is not about selling a product or argument, but about analyzing, understanding and reflecting what is inevitably happening anyways (see Blumenberg, 2009). Therefore, the reference to metaphors and stories (from A to B via C) is at the basis for both, the analysis and differentiation of imagined sociotechnical futures as well as for the analysis of their particular impact on present practice.

To give a subordinate role to the meaning of language in the comparison of stories, the representation is generalized into key-narratives of similar structure (Roßmann & Rösch, 2019; Viehöver, 2001). The stories are comparable in that they suggest an ongoing process in which a hero is faced with a challenge that he can solve through his highlighted unique and particular features, permitting a "happy ending", or respectively more general the narrative closure. Such stories can be found in introductions of papers justifying the research question, in newspaper articles, in lectures, in pictures, films, and in general at narrators who give meaning to their agendas by putting them in a framed context and ignoring for that moment the complexity of the world. Revealing such forms of coherence generation explains why different stakeholders arrive at different solutions, take other aspects into account and possibly reject each other's proposals. The juxtaposition of these stories makes it clear which other aspects are presently regarded as important or are not taken into account by the respective narrator.

What are the present visionary stories that have entwined with 3D printing and how do they relate to different social contexts? The key-narratives represent the visionary storylines that structure the societal discourse about future 3D printing. However, it is important to note that present state of our study only represents the visions that strongly circulated 2010 until 2015 which is roughly the time of the by now gone hype of 3D printing (Alvial Palavicino, 2016), a time of high expectations and high media exposure for 3D printing technologies and a time of the main formation of this discourse (Schneider, 2018). Further, subsequent empirical studies aim to match old aspects of the visions with novel ones in the light of the feedback from different

stakeholders to structure the bigger picture of the dissemination and evolution of the visions. Typically, the different visions highlight one or more features of the technology and place them in a larger context – while ignoring other aspects.

- Narrative 1: 3D printing to shape the world atom by atom and bit by bit

Key-Narrative[1]:

> *"The world of ideas and the practice of shaping of matter have been regarded as separate spheres for long enough. Now, the combination of computer-aided sensors and modelling with the digital control of matter through 3D-printing reveals incredible opportunities. While measurement and simulation reveal an ever-deeper understanding of natural phenomena, synthesis can both validate findings and enhance nature. Finally, 3D printing put the man in his rightful place on earth – we shape the world atom by atom and bit by bit."*

In cultural history there are predecessors to such universally capable machines:

- Certain strands of ancient philosophy introduced the idea that the world is numerically ordered and that mathematical analysis could reveal this inner rationality of the world (Nida-Rümelin & Weidenfeld, 2018, p. 20).
- Turing's universal machine or the von Neumann's self-replicating machine are foundational visionary ideas for cybernetics and computer science that have informed and inspired much research (Greenfield, 2018, p. 86).
- Neil Gershenfeld of MIT's Media Lab imagines 3D printing as an enabler for a future of "ubiquitous fabrication" where the "distinction between a machine and what it makes then disappears, as the materials themselves become programmable." (Gershenfeld, Gershenfeld, & Cutcher-Gershenfeld, 2017, p. 179) Gershenfeld expects exponential growth of technological capabilities that will lead us there in a few decades.
- Classical myths in antiquity, as well as folk and fairy tales, often imagine magical devices that produce whatever one wishes. In Greek mythology, for example, the 'cornucopia horn' could produce whatever one wants. Many science fiction stories take up these ancient myths and imagine highly powerful machines that can produce anything: the replicator in *Star Trek*, the matter compiler in *The Diamond Age*, programmable matter in *Transcendence* (Ferrari et al., 2018, pp. 45–49).

[1] The narratives presented in this publication are not citations, but reconstructions of narrative structures. Narrative structures are visible when a story is largely reduced to its key elements (nuclei), see Barthes and Heath (1987).

How do the imaginations of the technological power of 3D printing combine with visionary ideas of societal change?

- Narrative 2: 3D printing as a driver of the next industrial revolution

Key-Narrative

> *"Steam engine relieved us from physical labour and mass production made food and consumer goods cheaply available for everyone. The 3rd industrial revolution is characterized by the promises around the flexibility and outreach of 3D printing. Through 3D-printing, we develop ideas globally, transform the digital models to matter, prototype in diverse settings, and quickly spread new products and services on the market on a big scale – all at the touch of a button."*

This key narrative can be found in different variants, ranging from envisioned incremental changes to radical transformations.

- The incremental revolution is said to take place through more efficiency, customization, and speed. The story is that after rapid prototyping (the first industrial application of 3D printing) rapid manufacturing enables to produce customized products highly efficiently and closer to customers (Schwab, 2016).
- An elaborate and recent study on 3D printing proposes standardisation and intensification of educational programs for skilled workers to facilitate the sociotechnical integration in the German industry (Leopoldina, Acatech, & Akademienunion, 2020). Further cooperation between schools and companies is proposed to make the technology usable in training and to involve companies in the learning process. Thereby, the narrative is aligned with the special structure of the dual education system in Germany.
- The more radical visions of this imagined revolution see decentralized industrial structures emerging that are said to replace the big industries of the scale of the 20th century. Highly networked machines and organizations create flexible and more egalitarian structures across the globe, producing and innovating in ways that could not be conceived in mass manufacturing. With 3D printing, the dynamics and structures of the digital economy are said to become a determining factor for material production as well. Some argue that the theoretical abundance of digital information could lead to abundance in material things as well with printers producing whatever can be conceptualized in digital information. Such abundance could lead to an end of scarcity and replace capitalist markets for goods and competition, some argue (Bastani, 2019; Rifkin, 2014).

- Narrative 3: 3D printing for individual empowerment

Key-Narrative

> *"For far too long we have been dependent on large corporations to turn ideas into reality and had to settle for mediocre products for the average person. This is now over. With 3D-Printing becoming smaller, cheaper, more accessible and capable, literally "everyone" will use these powerful machines. On the one hand, we can produce our everyday objects according to our own ideas and needs. And even better, now everyone has the opportunity to become an entrepreneur with creative ideas and designs. The success of 3D printing is a success for individual freedom."*

- This visionary narrative has different twists, either focusing on consumers who transform to become producers of goods they use themselves (also called "prosumers", producing and consuming in the same act) or on creative people who could most easily become entrepreneurs and sell the products that their printers produce.
- Neil Gershenfeld, professor at MIT and one of the founders of the FabLab movement, linked the future of 3D printing to the past of computer. Similar to the personal computer so-called "personal fabricators" were envisioned to be used at home by individuals with similar effects to production as the digital media revolution (Gershenfeld, 2007). The FabLab movement (see below) strives globally to enable easy access to 3D printing and other digital production technologies and to empower individuals to use the technologies (www.fablabs.io)
- Anderson (Anderson, 2013), a key figure in US technology journalism, argued that 3D printing would be a revolutionary technology because it would allow individuals to easily become entrepreneurs. He depicts "makers" equipped with 3D printers as the creative, improvising and opportunity-taking entrepreneurs of the 21st century who start a new age of invention.
- The vision of individual empowerment is also powerfully used in so-called DIY prosthetics, where customized prostheses are 3D printed. Typically, this is done much more cheaply than by the medical industry and often with the direct involvement of the users themselves.
- A version of this vision with only limited empowerment can also be found in the idea that 3D printers allow consumers to simply download what they need and print it. Here, there is little active and creative involvement in the technology but the ways of distributing goods changes through the 3D printer, i.e. you no longer go to the store to buy things or order online

- Narrative 4: 3D printing for communal empowerment

Key-Narrative[2]:

> *"The 20th century was a world of individual consumers who were dependent on a provision from state or industry. With the internet, people got together and exchange ideas, knowledge, and visions among free and equal people – just like in a global village. This movement enters the physical world. Now, hubs form in a large network where people meet and transform the digital into material objects with means of 3D printers. At the centre of communal empowerment, 3D printing will change local economies, education and civic life."*

- 3D printing is said to owe itself well to new forms of organizing economic activities, so-called digital commons. Established in Free Software, Open Software or Wikipedia these commons make digital information and knowledge freely available, shareable and modifiable. Typically, a "community" coordinates and organizes such commons. For 3D printing, it is envisioned that digital information on objects to be printed and on assembling 3D printers could be widely shared as "open source" and thus making the technology and its products widely and freely or cheaply available. In fact, this has happened with small scale Fused Deposition Modelling 3D printing, which was popularized through the open-source project RepRap (www.reprap.org), a project that explicitly aims to make a self-replicating machine. The visionary question remains whether this can happen with other, more capable technologies of 3D printing (Schneider, 2018).
- Some see 3D printing as especially relevant in creating or changing community organizations. Most notably, the past fifteen years have seen a global spread of so-called FabLabs, maker spaces and other community workshops that employ 3D printing. These workshops organize local communities who collectively use 3D printing and share knowledge. Many of these organizations take the idea of digital commons into local contexts and work collaboratively face-to-face and at the same time digitally connected to others across the globe (Schneider 2018).
- Some public organizations such as libraries or schools imagine that the future of learning could also be transformed by giving access to these technologies and the skills they afford. Some libraries already have 3D printing areas.
- The municipality of Barcelona announced in 2014 that it wanted to become the world's first "FabCity" by 2054. The project emerged out of the FabLab movement and has become a global network of initiatives in cities around the globe. The idea is to create

[2] The history and social practices of this narrative is the core focus of Schneider (2018)

FabLabs in every neighbourhood of the city such that increasingly goods can be produced in the city. Within the next decades, digital data should move in and out of the city while material production is highly localized and part of a local circular economy. The project wants to empower local businesses and reduce the city's dependence on global supply chains. (https://fab.city/)

- Some activists and scholars in global development envision potentials of 3D printing for the global South. At a lower cost, decentralized, modular and lending itself to tinkering and improvisation 3D printing could modernize and empower local economies without the need to set up industrial structures. Plastic and waste could be recycled and used as material for the printers (Birtchnell & Hoyle, 2014).

- Narrative 5: 3D printing for resource efficiency and sustainability

Key-Narrative:

"There are 7.8 billion people on this planet and they all want our standard of living. Luckily, additive manufacturing is extensively applied to not shred and waste raw material in the future. Besides, 3D printing reduces environmental costs from transport and logistics by enabling you to download the necessary components on demand and print them out on site. Now, fascinating structures of equal or better stability can be created everywhere with a fraction of the material due to sustainable 3D-printing."

- Especially since the United Nations agreed on sustainable development goals and climate protection measures, but also due to the popularity of the climate movement, 3D printing enters the public stage in the mantle of sustainability.
- The ecological evaluations of 3D printing always highlight the promised savings in material and logistics (Keppner et al., 2018; Woodson, Alcantara, & do Nascimento, 2019). Besides, more efficient technology designs could be developed. Ecological framing is particularly used where resource savings also save money, e.g. by reducing the amount of expensive metal alloys used in aircraft construction. However, present life cycle assessments of 3D-printing are uncertain due to their very diverse applications. Therefore, the arguments for sustainability rely heavily on the distribution and generation of 3D-printing experiences that stabilize system boundaries and functional substitutes for modelling.
- The focus on resource efficiency and sustainability in 3D printing draws attention to the energy costs of lasers, the low durability and stability of products, the lack of recycling, the substitution of renewable raw materials (e.g. wood) by plastic and the use of solvents (Keppner et al., 2018). The elaborate material processing illustrates the ecological criticism, for example, when in an energy-intensive process inert gas is used

for atomizing metal powders which in addition require special health and fire protection measures (Leopoldina et al., 2020). Especially the rebound effect is emphasized, i.e. the waste of material in unnecessary things that one would not have produced without the printer.

- At present, the variety of application areas and components does not allow a general statement about the sustainability of 3D printing. Nevertheless, the story of 3D printing for resource efficiency has highly competitive technologies in the very prominent field of sustainable technologies. If the vision of sustainable 3D printing maintains its media presence, research will be motivated to conduct new studies which might uncover some visions as illusions. For the ecological evaluation of 3D printing in different areas, the interest in sustainability has to be translated into the request to collect data on components, lifetime, substitution and applications (see Leopoldina et al., 2020).

- Narrative 6: 3D printing to individually cure or enhance human capacities

Key-Narrative:

"Modern medicine ensures that health and old age is not a coincidence. But still, if functional body structures are missing or fail, people face permanent disabilities. Now, this frontier of medicine is exceeded, by merging living matter with the possibilities of 3d printed design and replication. Novel Bio-3D-printers make matter self-assembly to perfectly fuse tissues, dentures, prostheses, and even organoids with the individual body. Any doubts? Printed organoids also allow for the rapid testing of therapies – without additional animal suffering. The functional combination of 3D printing and self-organization complements modern medicine to give back control for a better life."

- Especially in medical-related areas, the greatest benefits and willingness to pay for individualized production are expected. By considering technology as an extension of the imperfect human, the claim for human capacity grows with the standard of technical possibilities and the individual perception of a disadvantage. The narrative structure bypasses questions of cultural-relative normality and acceptable suffering by emphasizing the subjective experience. Similarly, the visions of 3D printing in medicine have so far made no clear distinction between necessary and unnecessary applications.
- A recent comprehensive TA study on bio 3D printing analyses current trends in the field of medical applications and summarises them in four scenarios and derives challenges (Ferrari et al., 2018). While in this study the scenario funnel is structured along with

further possible events in the dimensions of governance vs. self-regulation and slow vs. fast progress, our single medicine narrative highlights the technological promises.

- The medical use of 3D printing is found in artistic and popular imaginaries. Examples are „ghost in a shell“, „the Fifth Element (1997)“, „The Printer's Devil (1996)“, „Seveneves (2015)“, „rule 34 (2011)“, and the DC comics „Transmetropolitan“ (1997-2002) (for clustering and analysis of cultural imaginaries see Ferrari et al., 2018, pp. 45–49). These cultural representations reflect the blur demarcation of medical necessity and the "unnecessary" perceived human enhancement, playing with health in bio-hacking, or singularity of man and machine. Therefore, ethical debates accompany the classification of medical applications.
- The printing of tissue and teeth, in particular, is already more developed. However, the TA study finds that the price of 3D printers makes it „highly unlikely“ that the technology finds its way to normal dentists and hospitals (Ferrari et al., 2018). Instead, in the nearer future, only medical centres like university hospitals are considered to use 3D printing technologies.
- While some clinical successes have been achieved with 3D-printed structures transplanted directly into the patient to promote controlled bone, cartilage and skin growth, there have been more limited successes in the production of blood vessels, nerves, skin and bone outside the body (Boucher, 2019, p. 6).
- (Partly) replacing living systems by synthetic organoids, both in transplantation and in the testing of new or individual therapies (e.g. Lab on a Chip), arises the question of functional equivalence. An organoid for testing mutagenicity is different from an organoid for testing irritation, and certainly will be very different from an organoid that is used for vision.
- Since the medical sector is legally strongly regulated to protect health as well as known for large profits and investments, a strongly non-linear innovation dynamic can be expected in this area while startups are likely to develop ideas without bringing them to market themselves (e.g., see Birch, 2017).

A recent report concludes that excessive expectations in science and the public concerning medical additive manufacturing should be met by open and transparent communication about the actual state of research and the technological capacities (Leopoldina et al., 2020, p. 80).

4 The futures of 3D printing after the first hype

The analysis of the public discourse on 3D printing shows that the first hype seems to be over. The first euphoria began around 2005 with the first open-source 3D printers and had a peak around 2013 and 2014. As the first open-source 3D printers appeared in 2005, also new forms of organization and online business models have emerged through the so-called Web 2.0. Social innovations such as FabLabs and Maker Spaces were on the rise where people met and shared their enthusiasm for 3D printing while also pointing to new horizons of production and consumption (Schneider 2018). Alongside with the success and general presence of social media and the search for new economic and more material horizons after the financial crisis of 2008, the FabLabs and Maker Spaces were on the rise. For example, the Karlsruhe FabLab opened in 2014 and considers itself part of a global movement that focuses on openness, communal education and experimentation, networking, and sustainability, according to their manifesto. Digitalization was considered ever more “real” and related to our familiar societal and material environment when Barack Obama in 2013 and 2014 repeatedly claimed that 3D printing has the potential to revolutionize manufacturing in the US (Obama, 2014). The vision of 3D printing reached the public, science, business, and politics. To give special weight to his claim, he even scanned and printed himself (Figure 3). From today's point of view, he has set a monument to the first hype about 3D printing.

Figure 3: 3D printed sculpture of Barack Obama, who is considered a prominent advocate of the claim that 3d print will revolutionize manufacturing. (http://gl.ict.usc.edu/Research/PresidentialPortrait/)

Hypes are very evident social phenomena related to new technologies and the visions entangled with them. In industry, 3D printing moved from being a rapid prototyping technology to a specialized production technique. Especially after the financial crisis of 2008, new narratives of industrial transformation emerged, such as “industry 4.0” (Schwab, 2016), that could easily include 3D printing. However, on the long run, 3D printing became less the focus

of attention but is rather regarded as established periphery in visions, which now seems to focus more on international competition, data as resources, robotics and algorithms. Hypes have an ambivalent character in shaping new technologies and can themselves be differently understood, as Table 1 shows.

Table 1: Different definitions of hype, adapted from Alvial Palavicino, 2016, p. 126

Hype as exaggeration	A practice of technology actors who strategically promote exaggerations related to a new technology that downplay possible negative aspects
Hype as increased media attention	Waves of media attention where positive and exaggerative stories are typically followed by more negative "news" related to new technology. Crucial for an early public understanding of new technologies.
Hype-cycle as an assessment tool	Used by the consultancy Gartner to assess (and promote) hypes of new technologies.
Hype as a folk theory	The belief that hypes are a recurring phenomenon related to new technologies that can give an insight into the development of a technology
Hype as a social phenomenon	Enthusiasm mobilises innovators to take risks and to create new spaces of possibility for new technologies.

By now we could say that 3D printing is after its first hype (Figure 4). The public attention to 3D printing has decreased since then. Critical voices have questioned whether there is a revolutionary potential in the technology or whether its widely available usages will remain confined to niches without revolutionising industry or even society (Daum, 2019).

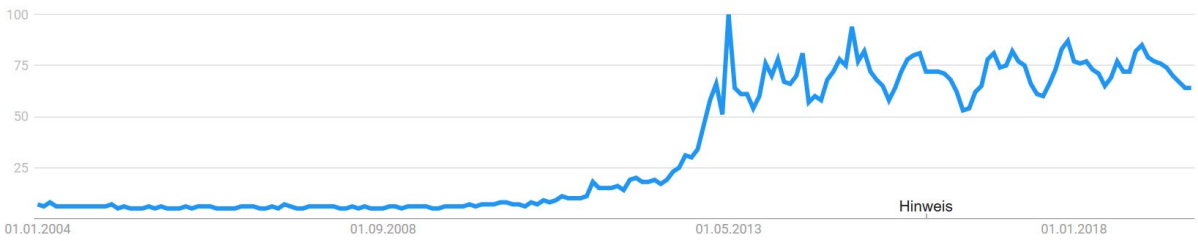

Figure 4: Google searches for the topic 3D printing peaked globally in 2013

5 Next steps

This draft analysis of the metaphors key-narrative represents the state of the research and serves as the basis for further empirical work aiming to validate or extend the clustering of future projections. Next, based on techno-sociological hermeneutics, we will explore the inner dimensions of future projectivity (see Mische, 2014). These include, for example, imagined time frames (realization in the near or distant future, clarity of imagination, contingency of occurrence), imagined agency (decisional or determined, shapeable or freedom-robbing), imagined societal transition context (realization of the future by politics, individual commitment, scientists, or industrial organizations). From these distinctions, implications for actions and motivation can be deduced. As a result, we expect a differentiated overview of present visions of (scalable) 3D printing and their stakeholders. These visions serve as a starting point for evaluating the pragmatism of visions as well as for assessing the feasibility and desirability of their future projections from a stakeholder perspective. The Vision Assessment study on scalable 3D printing thus aims to show options for action and to contribute to responsible research and innovation. Results will be mirrored back into the cluster to provide an orientation for further research and foster the reflexive dialogue with societal stakeholders.

5.1 The future of the Vision Assessment study

Accompanying actual research beyond the first hype is an optimal time for the Vision Assessment. Now that the hype is gone, there is a better opportunity for differentiated, reflexive and factual analysis and societal debate. It allows us to disentangle monolithic ideas of 3D printing and get into view the different technologies, application domains and context-dependent opportunities and risks. In 2020 and 2021 amongst other things we plan to:

- Host a public event on the futures of 3D printing at the Institute for Technology Assessment and Systems Analysis: www.itas.kit.edu (date postponed).
- Start interviewing stakeholders of scalable 3D printing: researchers, industry representatives, activists, and others to figure out in more detail how they envision the futures of 3D printing.
- Develop the first application scenarios of scalable 3D printing that include technological trends as well as social aspects to analytically distinguish different paths of sociotechnical change and open these up to assessment and debate. These scenarios will be closely linked to the technologies and applications that the cluster of excellence is working on.
- Hold a feedback dialogue within the cluster to discuss our work and get input for the technological side of the scenarios.

- Organise a major scientific symposium on the societal futures of 3D printing taking place in early 2021.

5.2 We welcome your feedback!

If you would like to ask something about the topics covered in this report, point us to insights and information you came across or give us your thoughts on the societal aspects of 3D printing we highly welcome your feedback. Please contact us at:

andreas.loesch@kit.edu

max.rossmann@kit.edu

christoph.schneider@kit.edu

6 List of figures

7 References

Alvial Palavicino, C. (2016). *Mindful anticipation: a practice approach to the study of expectations in emerging technologies.* https://doi.org/10.3990/1.9789036540605

Anderson, C. (2013). *Makers: The new industrial revolution*. London: Random House Business.

Aristoteles (2006). *Poetics* (J. Sachs, Trans.). Sachs, Joe (trans.). *Focus philosophical library*. Newburyport, Ma: Focus Publ.

Barthes, R., & Heath, S. (1987). *Image, music, text*. London: Fontana Press.

Bastani, A. (2019). *Fully automated luxury communism: A manifesto* (First published.).

Beckert, J. (2016). *Imagined futures: Fictional expectations and capitalist dynamics*. Cambridge, Massachusetts, London, England: Harvard University Press.

Birch, K. (2017). Rethinking Value in the Bio-economy: Finance, Assetization, and the Management of Value. *Science, Technology, & Human Values*, *42*(3), 460–490. https://doi.org/10.1177/0162243916661633

Birch, K. (2019). Technoscience Rent: Toward a Theory of Rentiership for Technoscientific Capitalism. *Science, Technology, & Human Values*, *45*(1), 3–33. https://doi.org/10.1177/0162243919829567

Birtchnell, T., & Hoyle, W. (2014). *3d printing for development in the global south: The 3D4D challenge*. *Palgrave pivot*. Basingstoke, Hampshire: Palgrave Macmillan. Retrieved from https://www.loc.gov/catdir/enhancements/fy1610/2014034491-d.html

Blumenberg, H. (2009). Anthropologische Annäherung an die Rhetorik. In H. Blumenberg (Ed.), *Universal-Bibliothek: Vol. 7715. Wirklichkeiten in denen wir leben: Aufsätze und eine Rede*. Stuttgart: Reclam.

Borup, M., Brown, N., Konrad, K., & van Lente, H. (2006). The sociology of expectations in science and technology. *Technology Analysis & Strategic Management*, *18*(3-4), 285–298. https://doi.org/10.1080/09537320600777002

Boucher, P. (2019). *3D bio-printing for medical and enhancement purposes: In-depth analysis*. Luxembourg: Publications Office of the European Union.

Bruner, J. (1990). *Acts of meaning*. Cambridge, Mass.: Harvard Univ. Press.

Castells, M. (2011). *The Power of Identity: The Information Age: Economy, Society, and Culture Volume II with a New Preface* (2., Auflage). *Information Age Series: Vol. 2*. New York, NY: John Wiley & Sons.

Daum, T. (2019, July 28). Missing Link: Der 3D-Drucker, oder: die industrielle Revolution, die nicht stattfand. *Heise Online*. Retrieved from

https://www.heise.de/newsticker/meldung/Missing-Link-Der-3D-Drucker-oder-die-industrielle-Revolution-die-nicht-stattfand-4480733.html

Ferrari, A., Baumann, M. F., Coenen, C. [Chr.], Frank, D., Hennen, L., Moniz, A. B., . . . Mordini, E. e. a. (2018). *Additive bio-manufacturing: 3d printing for medical recovery and human enhancement (STOA-Study IP/G/STOA/FWC/2013-001/LOT5/C2)*. Brüssel, Belgien.

Ferrari, A., & Lösch, A. (2017). How Smart Grid Meets In Vitro Meat: on Visions as Socio-Epistemic Practices. *NanoEthics*, *11*(1), 75–91. https://doi.org/10.1007/s11569-017-0282-9

Gershenfeld, N. A. (2007). *Fab: The coming revolution on your desktop - from personal computers to personal fabrication* (Paperback publ). New York, NY: Basic Books.

Gershenfeld, N. A., Gershenfeld, A., & Cutcher-Gershenfeld, J. E. (Eds.) (2017). *Designing reality: How to survive and thrive in the third digital revolution* (First edition). New York: Basic Books.

Greenfield, A. (2018). *Radical technologies: The design of everyday life* (paperback edition). London, New York: Verso.

Grunwald, A. (2019a). *Shaping the Present by Creating and Reflecting Futures.*

Grunwald, A. (2019b). *Technology assessment in practice and theory*. Abingdon, Oxon, New York, NY: Routledge.

Habermas, J. (2005). *Die Zukunft der menschlichen Natur: Auf dem Weg zu einer liberalen Eugenik?* (Erw. Ausg., 1. Aufl). *Suhrkamp Taschenbuch Wissenschaft: Vol. 1744*. Frankfurt am Main: Suhrkamp.

Jasanoff, S., & Kim, S.-H. (2013). Sociotechnical Imaginaries and National Energy Policies. *Science as Culture*, *22*(2), 189–196. https://doi.org/10.1080/09505431.2013.786990

Jonas, H. (1979). *Das Prinzip Verantwortung: Versuch einer Ethik für die technologische Zivilisation*. Frankfurt/M.: Suhrkamp.

Kahn, H., & Wiener, A. J. (1967). *The year 2000: A framework for speculation on the next thirty-three years*. Croton-on-Hudson: Hudson Inst.

Kahneman, D. (2012). *Thinking, fast and slow*. London: Penguin Books.

Keppner, B., Kahlenborn, W., Richter, S., Jetzke, T., Lessmann, A., & Bovenschulte, M. (2018). Focus on the future: 3D printing: Trend report for assessing the environmental impacts. Retrieved from http://nbn-resolving.de/urn:nbn:de:gbv:3:2-93853

Konrad, K., & Böhle, K. (2019). Socio-technical futures and the governance of innovation processes—An introduction to the special issue. *Futures.* Advance online publication. https://doi.org/10.1016/j.futures.2019.03.003

Kosow, H., Gaßner, R., Erdmann, L., & Luber, B.-J. (2008). *Methoden der Zukunfts- und Szenarioanalyse: Überblick, Bewertung und Auswahlkriterien*. *WerkstattBericht / IZT, Institut für Zukunftsstudien und Technologiebewertung: Vol. 103*. Berlin: IZT. Retrieved from http://www.izt.de/fileadmin/downloads/pdf/IZT_WB103.pdf

Ladikas, M., Hahn, J., Hennen, L., Kulakov, P., & Scherz, C. (2019). Responsible research and innovation in Germany – between sustainability and autonomy. *Journal of Responsible Innovation*, *6*(3), 346–352. https://doi.org/10.1080/23299460.2019.1603536

Lakoff, G. (2010). Why it Matters How We Frame the Environment. *Environmental Communication*, *4*(1), 70–81. https://doi.org/10.1080/17524030903529749

Lakoff, G., & Johnson, M. (2003). *Metaphors we live by: With a new afterword* (6. print). Chicago, Ill.: Univ. of Chicago Press.

Leopoldina, Acatech, & Akademienunion (2020, March 27). *Additive Fertigung – Entwicklungen, Möglichkeiten und Herausforderungen.* (Schriftenreihe zur wissenschaftsbasierten Politikberatung). Halle (Saale). Retrieved from https://www.acatech.de/publikation/additive-fertigung-entwicklungen-moeglichkeiten-und-herausforderungen/

Lösch, A., Böhle, K., Coenen, C. [Christopher], Dobroc, P., Ferrari, A., Heil, R., . . . Wentland, A. (2016). *Technikfolgenabschätzung von soziotechnischen Zukünften*. Retrieved from https://publikationen.bibliothek.kit.edu/1000062676 https://doi.org/10.5445/IR/1000062676

Lösch, A., Grunwald, A., Meister, M., & Schulz-Schaeffer, I. (2020). *Socio-Technical Futures Shaping the Present: Empirical Examples and Analytical Challenges*. *Technikzukünfte, Wissenschaft und Gesellschaft / Futures of Technology, Science and Society Ser*. Wiesbaden: Springer Vieweg. in Springer Fachmedien Wiesbaden GmbH.

Lösch, A., Heil, R., & Schneider, C. (2017). Responsibilization through visions. *Journal of Responsible Innovation*, *4*(2), 138–156. https://doi.org/10.1080/23299460.2017.1360717

Maasen, S., & Weingart, P. (2000). *Metaphors and the dynamics of knowledge*. *Routledge studies in social and political thought: Vol. 26*. London, New York: Routledge.

MacIntyre, A. (2007). *After Virtue: A Study in Moral Theory, Third Edition*. Notre Dame IN: University of Notre Dame Press.

Malone, E., Hultman, N. E., Anderson, K. L., & Romeiro, V. (2017). Stories about ourselves: How national narratives influence the diffusion of large-scale energy technologies. *Energy Research & Social Science*, *31*, 70–76. https://doi.org/10.1016/j.erss.2017.05.035

McCloskey, D. N. (1999). Storytelling in economics. In C. Nash (Ed.), *Narrartive in culture. The uses of Storytelling in the sciences, philosophy, and literature* (pp. 5–22).

McCray, P. (2013). *The visioneers: How a group of elite scientists pursued space colonies, nanotechnologies, and a limitless future*. Princeton: Princeton University Press. Retrieved from http://proquest.tech.safaribooksonline.de/9781400844685

Mische, A. (2014). Measuring futures in action: projective grammars in the Rio + 20 debates. *Theory and Society*, *43*(3-4), 437–464. https://doi.org/10.1007/s11186-014-9226-3

Nash, C. (2010). *Narrative in culture: The uses of storytelling in the sciences, philosophy, and literature*. *Warwick studies in philosophy and literature*. London, New York: Routledge. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&scope=site&db=nlebk&db=nlabk&AN=140470

Nida-Rümelin, J., & Weidenfeld, N. (2018). *Digitaler Humanismus: Eine Ethik für das Zeitalter der künstlichen Intelligenz* (2. Auflage, Originalausgabe). München: Piper.

Nordmann, A. (2016). Enhancing Machine Nature. In J. B. Hurlbut & H. Tirosh-Samuelson (Eds.), *Perfecting Human Futures* (pp. 195–214). Wiesbaden: Springer Fachmedien Wiesbaden. https://doi.org/10.1007/978-3-658-11044-4_10

Obama, B. (2014). *Remarks at the First Ever White House Maker Faire, June 18, 2014.* [Video]. Retrieved from www.youtube.com/watch?v=7wHorfRvvcE

Owen, R., Macnaghten, P., & Stilgoe, J. (2012). Responsible research and innovation: From science in society to science for society, with society. *Technological Forecasting and Social Change*, *39*(6), 751–760. https://doi.org/10.1093/scipol/scs093

Rifkin, J. (2014). *The zero marginal cost society: The internet of things, the collaborative commons, and the eclipse of capitalism* (1. ed.). New York, NY: Palgrave Macmillan.

Roßmann, M., & Rösch, C. (2019). Key-narratives of microalgae nutrition: Exploring futures with a public policy Delphi in Germany. *Science and Public Policy.* Advance online publication. https://doi.org/10.1093/scipol/scz053

Schneider, C. (2018). *Opening digital fabrication: Transforming TechKnowledgies*: KIT Scientific Publishing. https://doi.org/10.5445/KSP/1000083485

Schomberg, R. von, & Hankins, J. (2019). *International handbook on responsible innovation: A global resource.*

Schwab, K. (2016). *The fourth industrial revolution*. Cologny/Geneva: World Economic Forum.

Viehöver, W. (2001). Diskurse als Narrationen. In W. Viehöver, R. Keller, & W. Schneider (Eds.), *Handbuch sozialwissenschaftliche Diskursanalyse: ; 1. Theorien und Methoden* (1st ed., pp. 177–206). Opladen: Leske + Budrich.

White, H. (1980). The Value of Narrativity in the Representation of Reality. *Critical Inquiry*, *7*(1), 5–27. Retrieved from http://www.jstor.org/stable/1343174

Wittgenstein, L. (1984). *Werkausgabe*. Frankfurt a.M: Suhrkamp. Retrieved from http://www.geocities.jp/mickindex/wittgenstein/witt_pu_gm.html

Woodson, T., Alcantara, J. T., & do Nascimento, M. S. (2019). Is 3D printing an inclusive innovation?: An examination of 3D printing in Brazil. *Technovation*, *80-81*, 54–62. https://doi.org/10.1016/j.technovation.2018.12.001

KIT Scientific Working Papers
ISSN 2194-1629

www.kit.edu